

A PACKET SWITCHED FIBER - OPTIC COMMUNICATION LINK FOR COMPUTER NETWORKS

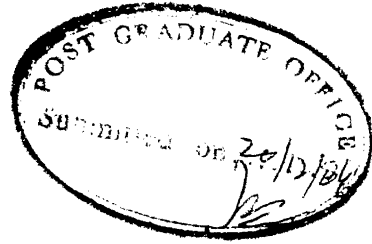
**A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY**

11/8

**By
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**to the
DEPARTMENT OF ELECTRICAL ENGINEERING *
INDIAN INSTITUTE OF TECHNOLOGY, KANPUR
DECEMBER, 1984**

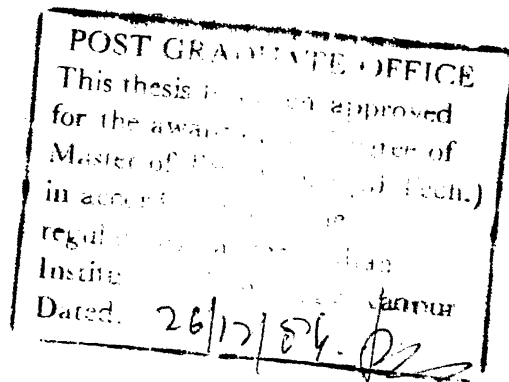
CERTIFICATE



Certified that this work entitled 'A PACKET SWITCHED FIBER OPTIC COMMUNICATION LINK FOR COMPUTER NETWORKS' has been carried out under my supervision by Mr. Mysore N. Ravi Kumar and has not been submitted elsewhere for a degree.

Dec. 19, 1984

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ABSTRACT

The achievement of low loss transmission has made the optical fiber waveguide, the leading contender as the transmission medium for a variety of future systems. The permeance of computers and terminals into every day life has lead to the need for computer networks. This thesis describes the design and implementation of a microprocessor controlled interface message processor to handle the data link layer protocol in a point-to-point optical fiber network.

A survey of the state of art in optic fiber channel based computer networks has been carried out. The implemented data link layer protocol is a subset of the ^{ISO/}CCITT's High level Data Link Control (HDLC) protocol. The system supports either a two party point-to-point link or a Multipoint Master/slave links. The IMP can support one master and 255 slave stations. The maximum speed achievable on the optical fiber link is 10 Mbs. For test purposes the data transfers are being done by the IMP's at 9.6 Kbps.

Minor hardware changes can be made to effect data transfers at 64Kbps. Finally, some upgradation schemes are explored.

CHAPTER 1

INTRODUCTION

1.1 GOALS OF COMPUTER NETWORKING:

The spread of computers and terminals into schools, offices, laboratories and industries is creating a growing demand for computer networks. The goals of computer networking are:

1. To make all programs, data, and other resources available to the user of the network without regard to the physical location of the user and the resources.
2. To exploit the advantages of functionally distributed computing. In this approach some of the machines are dedicated to perform specific functions such as file storage, data base management, terminal handling and so on. By making different machines perform different tasks, the goal is to make the implementation simpler or more efficient.
3. To provide higher reliability by providing alternative resources of computing power..

1.2 MERITS OF FIBER-OPTICS:

A computer network is a collection of computers, terminals, peripherals which are connected by means of a physical communication channel. Fiber-optics is rapidly emerging as a

practical, cost effective technology for data communications. Pulses of light travelling down optic fibers are fast replacing electrical signals transmitted over copper wires. The transmission of information over optic fibers offers many advantages, some of which are not available with any other technology:

- Complete input-output electrical isolation
- Complete protection against Electromagnetic Interference and also No Electromagnetic Radiation.
- The available bandwidth is larger than that of conventional communication channels.
- Losses are very small.
- Light in weight, small in size
- Chemically inert and Fire-resistant.
- Cost effective.

All these properties make optical fibers, the best transmission medium available today.

1.3 RESOURCES AND SCHEMES:

In our institute several computers, both large and small, are scattered in different locations. The largest system, of course, is the DEC-1090 system located in the computer center. The Electrical engineering department has it's own PDP-11/24 minicomputer. Similarly there are some other minicomputers located in different departments and

offices of the Institute. A similar situation exists within the EE Department. There are a number of workstations spread within the department. The workstations are stand alone microcomputers with limited main memory.

By linking together all these computers through a communication network, the overall computing power can be enhanced and at the same time improving reliability and increasing flexibility of each individual system. Therefore it is logical to think in terms of implementing a Local Area computer Network (LAN) with optical fibers as the medium for Communication. The large bandwidth of the optical fibers make it possible to multiplex a very large number of communication channels over a single fiber. Generally optical-fiber systems are used for point-to-point links. This is a suitable arrangement for applications where stations can be divided into groups, and stations in one group communicate with stations in other groups. Data is multiplexed at one end of the fiber - optic link and demultiplexed at the other end. ex: This design can be implemented to link the PDP 11, at EE department to the DEC 10, at the computer centre, which are geographically separated. Thus, the resources, library routines of the DEC10 can be shared by the users at the EE department. If the communication pattern does not allow grouping, i.e. all stations may want to communicate with each other, then a

network is needed. ex. 1) The work stations can be hooked to a large secondary store, which is centrally located. The optic fiber links can be used for achieving high speed data transfers to and from the secondary store. 2) The work stations can also be hooked to both the secondary store as well as to the ~~FD~~ ~~ELL~~ system. The high data rate of the optical fiber leads the network designer to consider a topology which uses as few a links as possible, so that the capacity of the fiber can be maximally shared. It is upto the network designer to implement an appropriate topology.

The present work has considered the feasibility of implementing such a scheme. This project work undertakes to design and implement a point-to-point optical fiber communication link between two intermediate message processors (IMP's). The IMP's are connected to the optic fiber link on one end and a host system on the other. The host hands down to the IMP a PACKET of data. The IMP achieves a transparent data transfer of the given PACKET to the destination IMP.

1.4 THESIS OUTLINE:

This thesis contains an introduction to Computer Networks and Fiber Optic communication along with a survey of the work in the field of fiber optic networks, in the second chapter.

Chapter 3 delineates the system architecture, giving the building blocks of the subsystems.

Chapter 4 is devoted to the implementation details, both Hardware and Software.

Chapter 5 presents some concluding remarks.

CHAPTER 2

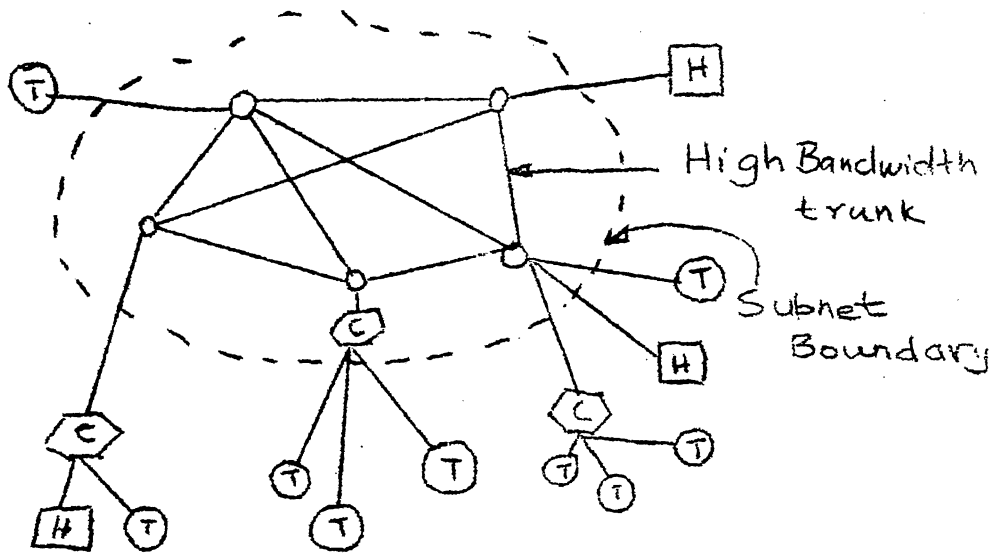
SURVEY OF COMPUTER NETWORKS AND FIBER-OPTICS

2.1 COMPUTER NETWORKS:

A Computer Network is a collection of computers called HOSTS, that communicate with one another. The hosts can be large multiprogrammed mainframes or even small personal computers. Networks can be classified as LOCAL AREA NETWORKS (LAN) or LONG HAUL NETWORKS. The hosts in a LAN are typically contained in a single building or campus and are connected by a high bandwidth cable or other communication media, e.g. optic fibers are large band width cables. Long haul networks typically connect hosts in different cities using public telephone lines or earth satellite or other media.

The communication facility in a long haul network is called the (communication) subnet, and often consists of mini-computers variously called IMP (INTERFACE MESSAGE PROCESSOR), NODES, or SWITCHES connected by high bandwidth channels or satellites. Fig. 2.1 shows a network using high BW lines. Such a network is called a POINT-TO-POINT or STORE AND FORWARD NETWORK, as opposed to a BROADCAST network, such as a satellite network.

Networks are almost organised as a hierarchy of layers. The ISO-OSI (International Standards Organisation - Open System



○ IMP ⬡ Concentrator □ Host ⊙ Terminal.

Fig 2.1 Point-to-Point Longhaul Network.

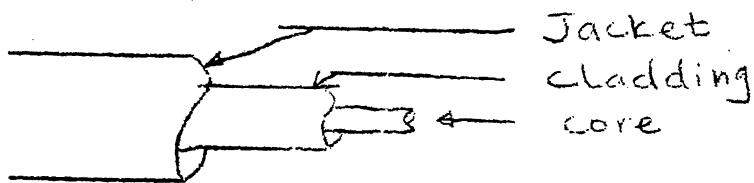


Fig. 2.2 Optical fiber

Interconnection) reference model can be used for both long haul and LAN. The ISO-OSI reference model has seven layers:

1. PHYSICAL layer
2. DATA LINK layer
3. NETWORK layer
4. TRANSPORT layer
5. SESSIONS layer
6. PRESENTATION layer
7. APPLICATIONS layer

All layers are present on the host whereas only layers 1,2,3 are present on the IMPS. Each layer can be thought of as a program or process (possibly embedded in a hardware device) that communicate with the corresponding layer on another machine. The rules governing the layer K conversation is called K layer protocol. The ISO model has seven layers. In reality data are not transmitted horizontally from machine to machine, within a given layer, but are passed VERTICALLY down the layers of the sending machine and up the layers in the receiving machine. Only in layer 1 does the actual inter machine communication occur [23].

The physical layer protocol is concerned with the transmission of a raw bit stream. It's protocol designers must worry about how 'one's' and 'zero's' are to be represented, how

many microseconds will a bit last, whether transmission is full-duplex or half-duplex, how many pins the network connector has, what each pin is used for and other electrical, mechanical and procedural details. The data link layer converts an unreliable channel into a reliable one for use by the network layer. The technique for doing so is to break up the raw bit streams into FRAMES (a collection of bits), each containing a CHECKSUM for detecting errors. A checksum is a short integer that depends on all the bits in a frame so that a transmission error will change it and thus be detectable. The data link protocol will ensure that a sender of data frame will retransmit the frame till an acknowledgement is got from the receiver.

The network layer in a POINT-TO-POINT network is primarily concerned with ROUTING and the effects of poor routing, namely CONGESTION. In a Broadcast network, routing is not an issue, because only one channel exists.

The task of the transport layer is to provide reliable host to host communication for use by the sessions layer, It must hide all the details of ^{the} communication subnet from the sessions layer, so that, for ex. a point to point subnet may be replaced by a satellite link with-out affecting the sessions, presentation and the application layers.

The sessions layer is responsible for setting up, managing, tearing down process to process connections, using the host to host service provided by the transport layer. It also handles certain portions of synchronisation and clock recovery. The presentation layer performs generally useful transformations on the data to be sent, such as text compression. It also performs the conversions required to allow interactive program to converse with any one set of incompatible intelligent terminals. The content of the application layer is up to the users. Nevertheless standard protocols for specific industries, such as airline and banking are likely to develop, although few exist now.

Although the ISO OSI reference model says nothing about how the layers are to be implemented, one possible configuration might have the physical layer in FIBEROPTICS, Data Link layer in a Special PROTOCOL CONTROLLER CHIP, the network layer in the device driver, the transport and the sessions layer in the operating system, the presentation layer in a set of library routines and the application layer be the user's program.

2.2 FIBER OPTICS:

The main subsystems of a Fiber Optic Communication System (FOCS) are:

- a. Optical Fiber
- b. Source and Transmitter
- c. Detector and Receiver

2.2.1 Optical Fiber:

The optical fiber is a dielectric waveguide (generally made of glass) consisting of a core region and a cladding region as shown in Fig. 2.2. The fiber is characterized by a profile of index of refraction as a function of the radial distance from the axis of the fiber. There are 3 types of fibers with different profiles of index of refraction as shown in Fig. 2.3. They are

- a.. Step index Single Mode Fibers
- b. Step index Multi Mode Fibers
- c. Graded index fibers

Consider a multimode fiber. Such a fiber has a index of refraction of n_c in the core region and n in the cladding region. n is lower than n_c . The core diameter is large compared to the wavelength of the light, therefore the propagation in a fiber can be modelled using geometrical optics. For a typical multimode fiber designed to operate at a wavelength of $0.8 \mu\text{m}$, one might have $n_c \sim 1.5$ and $n = 0.99n_c$ and core dia. = $50 \mu\text{m}$, cladding dia. = $125 \mu\text{m}$. Light propagation in a multimode fiber can be modelled according to Fig. 2.4. Ray1 is an AXIAL ray. Ray2 is a totally internally reflected ray. Ray3 will enter the cladding region and be absorbed. The axial rays and the totally internally reflected rays (TIR) are the ones that

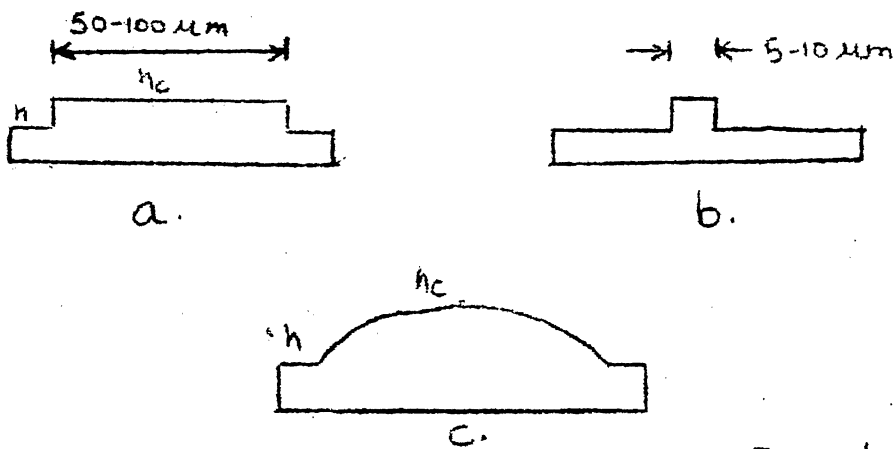


Fig 2.3 Refractive Index Profiles.

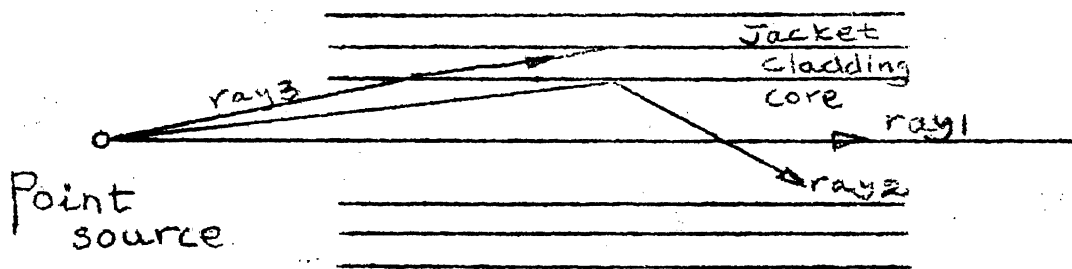


Fig 2.4 Propagation of Light in an optical fiber Cable.

constitute the effective light waves. The most significant I/O characteristics of an optical fiber are attenuation, bandwidth and coupling efficiency. The attenuation in fibers is governed by absorption (conversion of light energy into heat) and scattering (radiation of propagating light energy). [1]. Today's best reported (in the lab) transmission fibers have attenuations which approach the limit set by Rayleigh scattering (due to molecular inhomogeneities of the glass). At $0.8 \mu\text{m}$ the Rayleigh scattering limit is about 2.1 dB/km. Commercial fibers are available with losses of about 2.5-3 dB/km.

The bandwidth of a Multimode fiber is primarily controlled by two mechanisms: modal delay spread and material dispersion. Modal delay spread refers to the difference in group delays of the different wave guide modes (rays). From Fig. 2.4 it can be seen that a ray which travels AXIALLY will reach sooner than the TIR ray, inspite of them both originating at the same time. The modal delay spread can be controlled by having a small diameter core (step index Single Mode fiber) or by a Graded Index fiber. Material Dispersion refers to the variation in the group velocity of light in glass with the wavelength. This can also cause Pulse Spreading in fibers driven by Incoherent sources, such as LED's. At $0.8 \mu\text{m}$ wavelength, the group delay variation is about 100 ps/nm/km.

In general it is easier to couple light rays into a fiber with a larger core and a larger cone of propagating rays (larger acceptance angle). For a incoherent sources, such as LED's the amount of power coupled into a fiber is essentially proportional to the product of the fiber core area and the solid acceptance angle. For laser sources, efficient coupling to even single mode fibers is possible, provided that the laser maintains a well defined mode pattern and that it is properly matched to the fiber with an appropriate lens. However, as a practical matter, it is much easier to couple a laser to a Multi Mode fiber. More details pertaining to

1. Attenuation [2].
2. Coupling losses and multiplicative noise [3]
3. Fiber strength, Cabling [4]

can be found in references.

2.2.2 Sources and Transmitter:

Light sources for fiber optic communication systems must be compatible with the application. They must be small, efficient in conversion of prime power to launched light power, easy to modulate, reliable and low in cost. Two types of light sources have emerged as prime candidates for many applications. Light Emitting Diode (LED) and Injection LASER Diodes (LD). LED's are operated in forward bias and emit

light when holes and electrons combine at the p-n junction. Modulation is achieved by varying the drive current. A suitable driver circuit must provide high modulating current (10-100 mA) into the relatively low impedance of the forward biased junction.

2.2.3 Detectors and Receivers:

A receiver consists of a photodetector, which converts optical power into current, a buffer amplifier and an AGC amp. Fig. 2.5 shows a typical receiver. Detectors are normally p-i-n diodes. In a pin diode $\frac{1}{\lambda}$ the absorbed photons generate hole electron pairs at a maximum rate of one useful pair per photon. This corresponds to a maximum conversion ratio (Responsivity) of 0.8 A/W at 0.8 μm wavelength. Incident photons which are not absorbed (which are reflected) or whose generated carriers recombine before producing an output displacement current can be accounted for by defining a Quantum Efficiency for a given diode. In some applications it is advantageous to design a detector which produces more than one electron-hole pair per absorbed photon. An avalanche photo diode (APD) uses the mechanism of impact ionization to achieve this.

Amplifiers for use with photodetectors must be designed to introduce as little noise as possible because the fiber optic channel is virtually noise free. Fig. 2.6 shows a typical Fiber Optic Communication System.

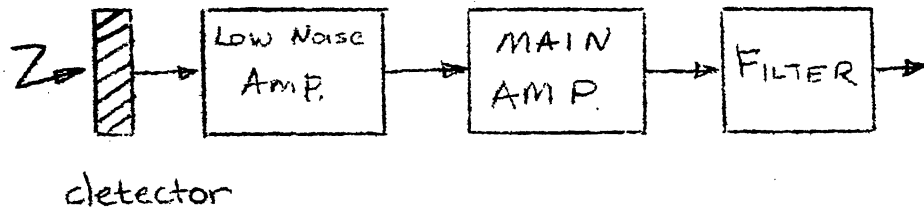


Fig. 2.5 Fiberoptic Receiver.

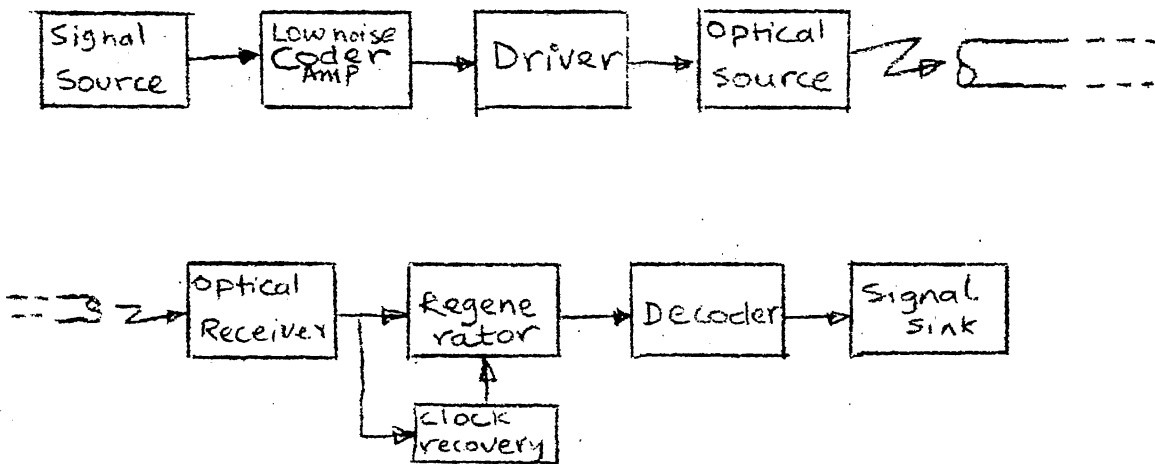


Fig. 2.6 Fiber Optic Communication System.

2.3 STATE-OF-ART:

Efficient system operation can be guaranteed if one exploits the advantages offered by transmitting coded data rather than raw data. The coded data can be used for error detection and error correction. Many schemes have been developed over the years. The present research has reached limits where a new line code which has been developed which is suitable for a high speed optical digital transmission system operating at 400 Mbps [5].

A new type of multiplexing is emerging due to the growth of the fiber optic communication systems. The Wavelength Division Multiplexing (WDM) is a scheme where the concept is 'the simultaneous transmission of the modulated emissions of several sources operating with different wavelengths over a single optical waveguide' [6].

Fiber optic communication systems in the wavelength division multiplexing mode are a development that in many cases allows the more efficient utilization of the large bandwidths of the optical fibers.

The receiver design must be carefully thought of, to produce as less noise as possible, because fibers do not produce much noise. An excellent approach to a good, low noise, high performance receiver design can be found in [7].

Progress in fabrication technology, splicing and laser technology is making single mode fibers practical for longhaul and under sea applications. In the lab. researchers have demonstrated transmission of signals at rates beyond 100 Mb/s over more than a 100 km of single mode fiber without repeaters. Presently administration in Europe, Japan, North America are experimenting with 'Broad band distributed systems' [8,19], providing users with voice, data, video and other services over an integrated network based on fiber transmission technology.

The increasing trends towards digital or digitized forms, along with rise in integrated circuit clock frequencies, point to optical fibers as the natural solution to the inter-connection of modules and even monolithic devices. The unique property of optical fibers with regard to noise immunity and electromagnetic compatibility are particularly important in 'local area network' applications. It is widely anticipated that decreasing fibers and electronic prices will make these systems more economical.

Local data communications includes the use of dedicated point to point links which are network links as well as non-network links e.g. CPU to Disk. The key character of a network in this context is that it is a shared resource.

The message transmitted on a link may have the source/destination addresses that are different from the addresses of the terminating equipment of that link. Therefore the most practical implementations of a local area network using fiber-optic technology will be active point to point links[9].

The very high data rate of the optical fiber leads the network designer to consider a topology which uses as few links as possible so that the capacity of the fiber can be maximally shared. To this end, a bidirectional bus structure, like Ethernet seems to be the best. However, it is difficult to implement low-loss bidirectional taps for transmission and reception. This feature leads the designer away from bidirectional structure. Rings, starshaped buses, and unidirectional buses are other alternative structures for optical LAN's. Studies on the advantages and disadvantages of buses and rings networks do not draw any conclusion favouring one or the other [10].

Since a ring network uses a one-way point to point transmission, replacing the wire links in a ring network with optical fibers is a very good application [11]. The Cambridge Ring operated for some time with one fiber optic link.

Another variation of the ring topology is the major and minor ring architecture [12]. Optical data high-way is a new general purpose local area network with ring topology. It is composed of two types of data highway based upon the same design of architecture, the minor ring and the major ring. The combination of major and minor rings can meet the various requirements providing a variety of system configurations

The advent of optical fibers into field of networking began in the mid of 70's. Then, a few experimental networks were designed and tested. In 1976 Xerox came up with a fiber optic version of the famous Ethernet [13]. After that, many new fiber optic networks have come into existence.

The FIBERNET-I was a passive-star configured network. FIBERNET-II [14] is the later version, and is an active-star configured network. Bidirectional data transfer of 10 Mb/s occurs between the active star and the fibernet transreceivers over duplex optical cable. When a station transmits on an idle network, the active star repeater detects the optical signal on the inbound optical fiber, electrically regenerates its amplitude, and optically transmits it to all stations via the outbound fibers. The minimum peak power injected into the fibers is 100 mw . The cables have a 6 dB/km attenuation. The receiver uses a p-i-n diode with a

transimpedance amplifier front-end. The receiver has a sensitivity better than -28 dBm.

Hubnet [15] is a packet switching LAN using glass fiber, as a communication medium. It operates at data rates of 50 Mb/s. It uses a dual rooted tree structure with twin fiber communication paths as shown in Fig. 2.7. The two trees are the broadcast tree and the selection tree. The outgoing arrows depict the broadcast tree and the incoming ones the selection tree. The Hubnet's frame structure is as shown in Fig. 2.8.

A packet to be transmitted is placed in the transmission buffer by the microprocessor program operating in the Network Access Controller (NAC). The packet will remain in this buffer until it appears to have been successfully sent to its intended destination. A NAC contains a MC68000 Microprocessor, a storage pool for packets and code storage, and an interface to the host.

S/Net [16] is a high speed small area Interconnect that supports effective multiprocessing environment among independent processors. In a multiprocessing environment it is necessary that programs on different processors be able to send messages to each other quickly. In the S/Net the processors communicate with each other with a high speed

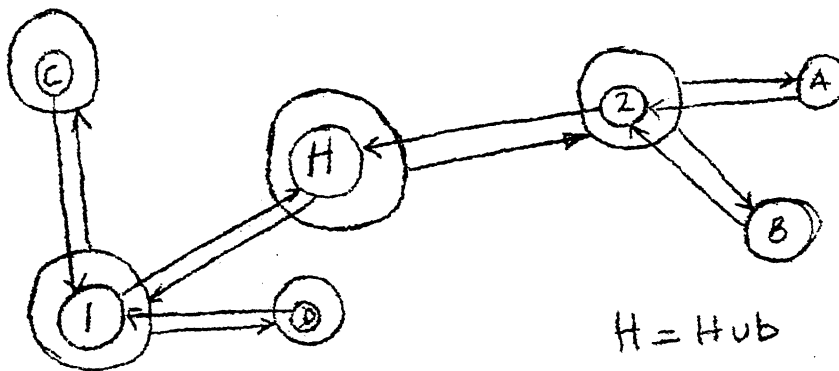


Fig. 2.7 HUBNET

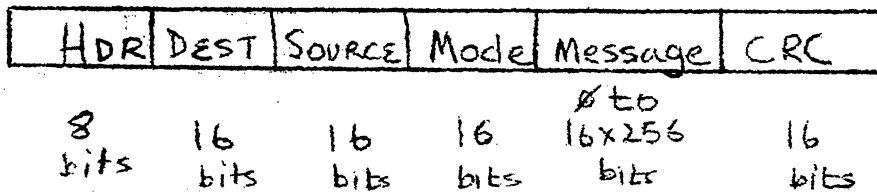


Fig. 2.8 HUBNET FRAME FORMAT

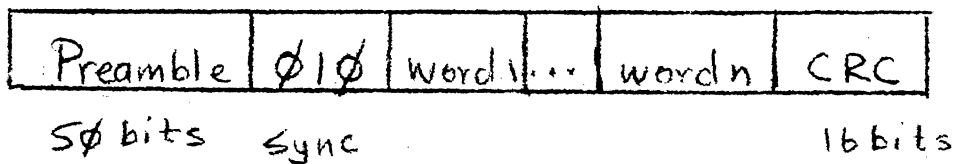


Fig. 2.9

packet switch via fiber links. Each link has two fibers one for each direction of data transfer. The links represent only point-to-point connections and fibers represent proven technology for such considerations.

Another high-speed fiber optic data bus for local data communication has been developed as a part of the NASA data base management system for achieving and retrieval of satellite data [17]. It operates at 100 Mb/s and is capable of handling 16 terminals separated by up to 2 km. The optical star coupler is the central component in its fiber optic bus and provides interconnection between all the bus interface units. The coupler performs the function of dividing optical power entering any one of its input ports equally among all of its output ports. A coupler manufacturing technique which has demonstrated good efficiency and uniformity is the fused Biconical Taper (FBT) process. An FBT coupler is fabricated by removing the buffer material to expose the outer surfaces of the optical fibers. An apparatus is used to twist the optical fibers together while maintaining uniform tension. The twisted portion is heated to the softening point and a taper region is formed. The packet format consists of a 50 bit preamble of 1's, a 010 sync. pattern, the message consisting of any integer number of 16 bit words and a 16 bit CRC as shown in Fig. 2.9.

The data is Manchester encoded. The 'Dynamic Time slot allocation' protocol has been employed to coordinate the channel accesses.

Apart from above, many more fiber optic networks have been designed and tested among which Expressnet [18], C-Net, D-Net [10] are just a few. Each of them adopt different topologies and differ in terms of performances.

CHAPTER 3

SYSTEM ARCHITECTURE

The system architecture is a vital aspect of all design procedures. The system architecture provides a gross view of the machine to the user, programmer or the engineer. The system architecture depicts the various building blocks at a module level and proves as a guideline for a better understanding of the system. A simple breakup of the implemented fiber optic link can be done as

1. Fiber optic communication system
2. Intermediate message processor

These two are discussed below.

3.1 FIBER OPTIC COMMUNICATION SYSTEM DESIGN:

A general point-to-point fiber optic link can be as shown in Fig. 3.1. The fiber optic communication system consists of the fiber optic transmitter, fiber optic receiver and the optical fiber cable.

The fiber optic transmitter will convert the electrical signals into optical signals. It has a Light Emitting Diode (LED), which is the light source for the optical fiber channel. The output power of the LED must be proportionate to the length of the optical fiber cable.

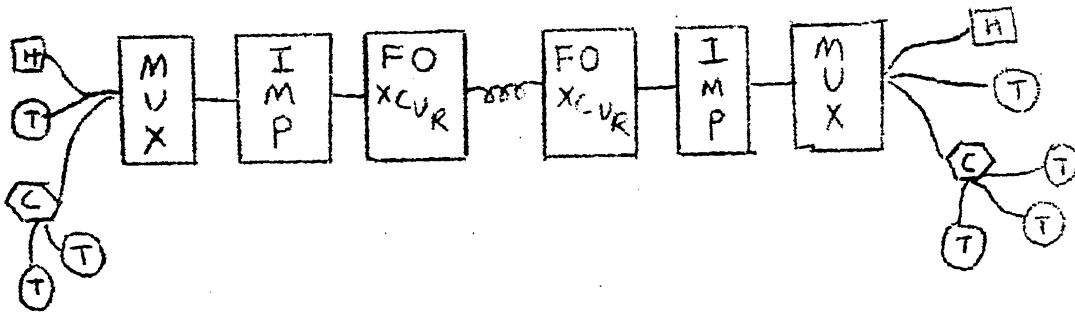


Fig. 3.1 A Typical Fiber Optic
point-to-Point Link.

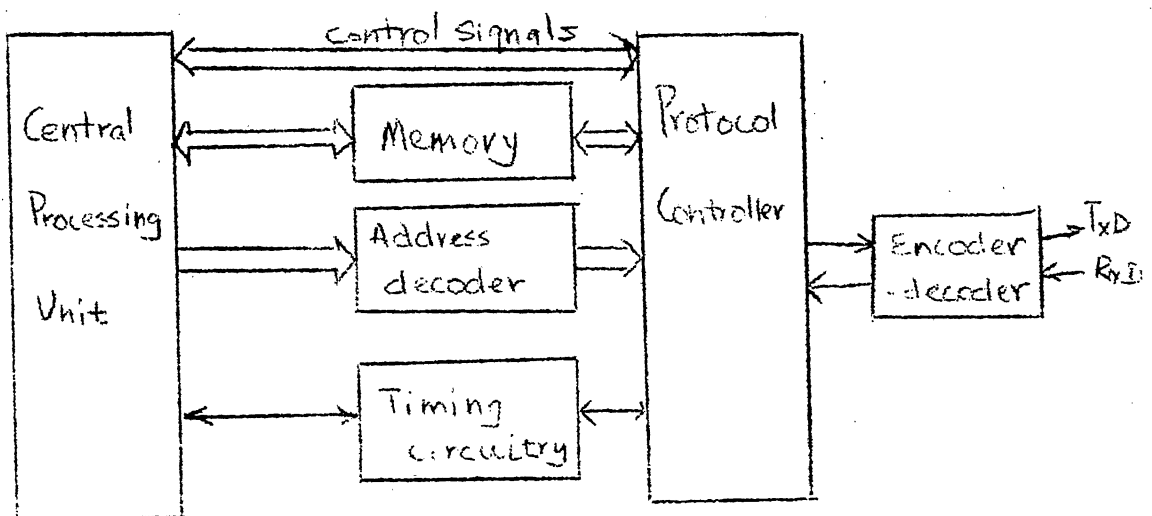


Fig. 3.2 Functional Block diagram
of the IMP

The receiver has a photodiode which will reconvert the light energy into electrical signals. The received signal will have small amplitudes, hence a preamplifier stage is needed in the receiver. The outstanding feature of optical fiber is that it introduces very little noise in the channel, hence the receiver must have a low noise amplifier.

The above are the general design constraints for the fiber optic transmitter and receiver.

3.2 INTERMEDIATE MESSAGE PROCESSOR DESIGN:

The functional block diagram of the intermediate message processor (IMP) is shown in Fig. 3.2. The IMP consists of memory, central processing unit, timing circuitry, address decoder, data encoder-decoder and the protocol controller.

3.2.1 Memory:

The memory comprises of Read Only Memories (ROM) and Read/Write Memories (RAM). The ROM contains the software of the protocols. The RAM is used for storing the data received from Hosts and IMPs. The data buffers are used by Hosts to put in the data to be transmitted. The IMPs use the data buffers to store the received data from other IMPs. A buffer management policy must be enforced for the prevention of congestion and enforce flow control. The Buffer Management policy implemented features the following:

1. The buffer must contain a maximum of 8 packets, i.e. 8 packets for transmission and 8 received packets as a maximum.
2. The maximum packet length must not exceed 256 bytes.
3. The Host can access the transmit buffers and update it whenever information is to be sent.
4. The Host can access the receive buffer and update it whenever a packet of data has been received. Messages are printed on the screen whenever the transmit buffer is full or whenever the receive buffer is empty.

3.2.2 Central Processing Unit:

The CPU controls the activities of the IMP. The control code, which is the protocol, is accessed from the ROM and executed. It has a priority resolver for the various interrupts from the devices. It provides the read, write and status signals needed for the control bus, to which all peripherals are attached.

3.2.3 Timing Circuitry:

The timing circuitry provides the clocks needed for the system. It also produces interrupts on time-outs. It also provides a circuit for recovery of clock from the received data.

3.2.4 Address Decoder:

There are a many ICs on the circuit. The question is 'how do we choose the one we wish to use?' The address decoder provides a logical low signal on one of its output pins depending on the status of its input lines. The outputs are used to select the various devices on board.

3.2.5 Encoder-decoder:

The encoder codes the input data bits into another format and inputs it to the modulator in a suitable form. The decoder will decode the received data to unravel the information .

3.2.6 Protocol Controller:

The protocol controller implements most of the functions of the data link layer. The data link protocol used is a subset of the international standards organization's (ISO) High level Data Link Control (HDLC) protocol. The functions accomplished by the protocol controller are flag generation, flag detection, check sum generation and checking, bit stuffing, destuffing, address recognition, framing and interrupt generation.

The next chapter discusses the implementation details of the system.

CHAPTER 4

SYSTEM IMPLEMENTATION

This chapter is organised under the following sections:

1. Fiber-optic link
2. IMP overview
3. IMP hardware
4. IMP software

The implementation details are discussed under each section.

4.1 FIBER OPTIC LINK:

The fiber optic link consists of the fiber optic transmitter, fiber optic receiver and the optical fiber cable. The transmitter and receiver are both digital i.e. they transmit and receive digital signals.

4.1.1 Fiber Optic Digital Transmitter:

The Hewlett-Packard fiber optic digital transmitter, HFBR-1001 has been used. The HFBR-1001 is an integrated electrical to optical transducer designed for digital transmission over single fiber channels. A bipolar integrated circuit and a GaAsP Light Emitting Diode convert TTL level inputs to optical pulses, at data rates from 0 to 10 Mbps. Typical power consumption is less than 500 mW. The schematic

diagram, emission spectrum and characteristics of HFBR-1001 are given in Appendix.

4.1.2 Fiber Optic Digital Receiver:

The receiver employed is the Hewlett-Packard HFBR-2001. The HFBR-2001, fiber optic receiver is an optical to electrical transducer, designed for data reception over single fiber channels. A silicon PIN photodetector and a bipolar integrated circuit convert optical pulses to TTL compatible outputs, at data rates from 0 to 10 Mbps. The optical sensitivity is 0.8 μ W. An integrated optical connector provides easy interfacing without any problems of fiber-detector alignment. The HFBR-2001 is a low noise receiver with a bit error rate of 10^{-9} . The characteristics and the spectral response of the HFBR-2001 is given in the appendix. An additional TTL output called the link monitor provides a digital indication of link continuity independent of the presence of data. Link continuity is indicated by a logical high output state. A low link monitor output indicates that the optical signal path has been interrupted. For example, it might indicate a broken line or a loose, dirty or damaged connector.

4.1.3 Optical Fiber Cable:

The Hewlett-Packard HFBR-3000 fiber optic single channel cable/connector has been used. The connectors mate

directly with the optical ports on the transmitter and receiver. The cable uses a single fused silica, partially graded index, glass clad fiber surrounded by silicone coating, buffer jacket and tensile strength members.

The combination is then covered by ^ascruff-resistant outer-jacket. The cable is resistant to mechanical abuse, immune to Electromagnetic Interference and is fire resistant.

The cable is 50 meters long. The cable characteristics are given in appendix.

4.2 INTERMEDIATE MESSAGE PROCESSOR OVERVIEW:

The IMP offers the services of the physical layer, data link layer and the network layer of the ISO-OSI reference model. The following sections discuss some of the features of the implemented systems with reference to particular layers.

4.2.1 Physical Layer:

The physical communication channel is the optical fiber. Data rate is 9600 bps. The link is serial. A TTL high level signifies a 1 and a TTL low level signifies a \emptyset . The data is encoded in the Non-Return to Zero Invert (NRZI) code. The optic fiber link input and output is TTL compatible.

4.2.2 Data Link Layer:

As seen from above, the physical layer protocol makes no attempt to detect or correct transmission errors. Nor does

it recognize the possibility that the receiver cannot accept data as fast as the sender can transmit them. Both these problems are handled in the data link layer. In the following sections the functions of the data link layer are explained.

4.2.2.1 Framing:

The approach used in the data link layer is to partition the raw physical layer bit streams into FRAMES, so that each transmitted frame can be acknowledged. An obvious question is 'How are frames delimited?', How can the receiver tell where one frame ends and the next one begins?

Flags are frame delimiters. Flags are characters with binary configuration $\emptyset 111111 \emptyset$. A frame is a sequence of data organized in a specific format. The HDLC format for a frame is as shown in Fig. 4.1.a.

a) Flags:

Flags are frame delimiters. They enclose the packet. The beginning flag initiates transmission error checking, the ending flag terminates the check for transmission errors. Flags have the binary configuration $\emptyset 111111 \emptyset$.

b) Address:

Address field contains the address of the sending station. This field is one byte long.

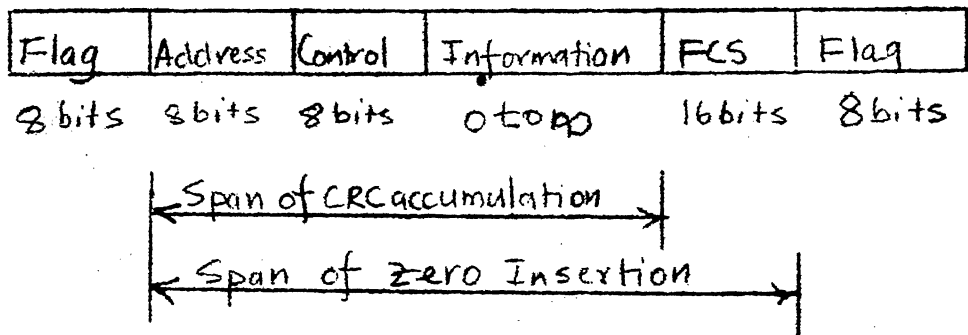
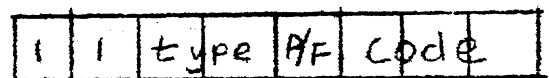
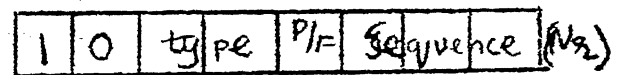


FIG. 4.1.a HDLC Frame Format.

Un-numbered



Supervisory



Information

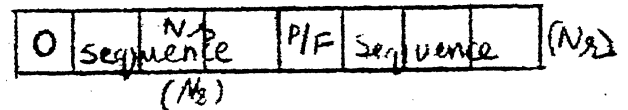


Fig 4.1.b Control bytes for the 3 types of frames.

c) Control:

The byte of data in this field determines the type of the frame. The control field content can be decoded to classify the frames into 3 types viz. a) un-numbered, b) supervisory, c) information.

Un-numbered frames are used for initializing a station and controlling the response. Supervisory frames provide confirmation for received frames, convey busy or ready conditions of the station. The control field formats are shown in Fig. 4.1.b.

d) Information Field:

The information field will contain the data for communication. The length of information is not fixed. It is fixed by the maximum buffer space available. Supervisory and control frames do not have an information field.

e) Frame Check Sequence:

The frame check sequence is a binary number. This number is arrived at by performing certain operations on the contents of address, control and information fields. The computation results in a cyclic redundancy check code. The receiver performs another computation and checks the validity of the received frame. Thus, the errors introduced by the communication channel can be detected.

4.2.2.2 Bit Stuffing/Destuffing:

The frame can be identified because the flags act as delimiters. To prevent the occurrence of the bit pattern $\emptyset 111111 \emptyset$ within a frame, the zero bit insertion technique is employed at the transmitter and at the receiver, the zero bit deletion is employed. A binary \emptyset is inserted by the transmitter after the occurrence of five contiguous 1's within a frame. Similarly the inserted 0's are deleted at the receiver.

4.2.2.3 Flow Control:

Consider a host A wishing to send data to another host B over a perfectly reliable channel. At first glance you might think that A could just send at will. However, this idea does not work, since B may not be able to process the data as fast as they come in. If B had infinite buffer space, it could store the input data for subsequent processing. Unfortunately, no host has infinite storage. Consequently, a mechanism is needed to throttle A into sending no faster than B can process the data. Such mechanisms are called flow control algorithms. The simplest of these algorithms, STOP-and-WAIT has been implemented. This protocol works as follows.

The sending station will put the sequence number of the packet in the code sequence N_s of the information frame. The

receiver has a counter which contains the sequence number of the expected frame. On successful reception of the information frame, the sequence number of the received frame is checked to see if it is the expected one. If it is, then the frame is accepted and the acknowledgement for having received the frame is sent with the sequence number of the frame received put in the code sequence of the control field (N_r). The counter is then incremented in anticipation of the next frame. The sender will keep sending the same frame with the same sequence number until an acknowledgement is received. The sequence number of the packet is incremented modulo 8.

4.2.2.4 Error Handling and Control:

All frames are transmitted upto a maximum of eight times, within which a positive acknowledgement must be received. Failing which, the appropriate error messages are displayed on the screen. A counter keeps count of the number of retransmissions. A time-out interrupt is used to cause a retransmission. If an information frame gets damaged, retransmission recovers the frame. If an Acknowledgement frame gets lost then the sender time-outs and retransmits same frame. The receiver finds the duplicated frame by checking the sequence number, rejects it and again sends an acknowledgement for the frame.

4.2.2.5 Buffer Management:

The Transmit and Receive Buffers each are 2K bytes in size. They can store eight packets of a maximum length of 256 bytes. The input data is packetized and stored in the buffers. The incoming data is not permitted to be stored in the buffer unless an empty buffer is found. A Tx buffer will be deemed empty only when it receives an acknowledgement from the other station. A Rx buffer will be deemed empty, when its contents are displayed on the screen.

4.2.2.6. Link Set up and Close Down:

The link set up involves the transmission of a supervisory frame and getting an Acknowledgement indicating the busy/ready condition. Close down again involves the Exchange of supervisory and acknowledgement frames indicating each other that the logical connections between them has to be snapped.

The above functions comprise the services offered by the data link layer.

4.2.3 Network Layer:

The services of this layer are many. The implemented SW does packetization, the input data is transformed into packets of a maximum of 256 bytes and is stored in the transmit buffer. The received packets are transferred to the Host in the sequence in which they were received.

The Network layer is responsible for handing packets to the data link layer. This handing down requires the packet of data to be placed in the buffers accessible to the data link layer protocol. This function is performed by software routines. Very short messages lead to inefficient operation, because of the Network overhead. There is an acceptable message length that provides an acceptable compromise between overhead and response time. It is not convenient, however, to force all network users to limit all messages to this length. This suggests the following mode of operation. Variable length messages may be accepted, and then, broken down into smaller messages that correspond to the optimal message length. This process is called packetization. Let us see what packet switching is, then. With packet switching, the user initially sets up a connection between his terminal or host and the nearest IMP, not the destination host. The destination host is also connected to an IMP. Whenever the user has data to send, he sends them to the IMP as a series of packets. Packets are routed from IMP to IMP within the subnet, until they get to the IMP which services the destination host. No circuits are reserved in advance within the subnet for Host to Host connection. Instead, the high bandwidth IMP-IMP lines are dynamically shared among all users on a demand basis. IMP-IMP lines are tied up only when data are actually being transmitted.

Implemented frames:

Format	Control word	Type	Name
Unnumbered	1111x100	Command	Set Asynchronous Balance Mode
Unnumbered	1100x010	Command	Abort
Unnumbered	1100x110	Response	Unnumbered Acknowledgement
Supervisory	1000xN _r	Response	Receiver Ready
Information	0N _s xxxx	Command	Information frame

Set Asynchronous Balance Mode: This command initiates a logical link set up, between two stations.

ABORT : This command terminates the logical link between two stations. This command can be given by either of these two only.

Unnumbered Acknowledgement: This is an affirmative response to a SABM and ABORT command.

Receiver Ready : This is an acknowledgement frame sent by one station to confirm the successful reception of an information frame.

Information frame: The information frame contains the data to be transferred. The control byte also has the 3-bit sequence number of the frame being transmitted.

4.3 IMP HARDWARE:

The intermediate message processor is a 8085 CPU based system. The IMP card is built as an appendage to the existing work stations. The block diagram of IMP-HOST is shown in Fig. 4.2.

The work station supports the CPUs, memory both ROM and RAM, USARTS, Keyboard/CRT controller and timer. The demultiplexed address, data and control bus is available on an edge connector. The pins of 8085 have been brought out on the 40 pin connector. The video monitor and the ASCII keyboard are controlled by a separate 8085 CPU. It reads the characters from the keyboard, and sends them serially to the CPU of the IMP via an USART. It displays the keyed characters on the screen. It also has its own 2K RAM for storing the characters constituting the 24 rows by 80 character page displayed on the monitor.

The Protocol Controller is an appendage to the existing CPU, timer and memory of the work station. The timer is used for generating the time-out interrupts. The output of the timer is wired to the RST 6.5 interrupt. The work station has 8K bytes of RAM, with addresses from 4000H to 5FFFH. The memory map and port addresses are shown in Table 4.1 and Table 4.2.

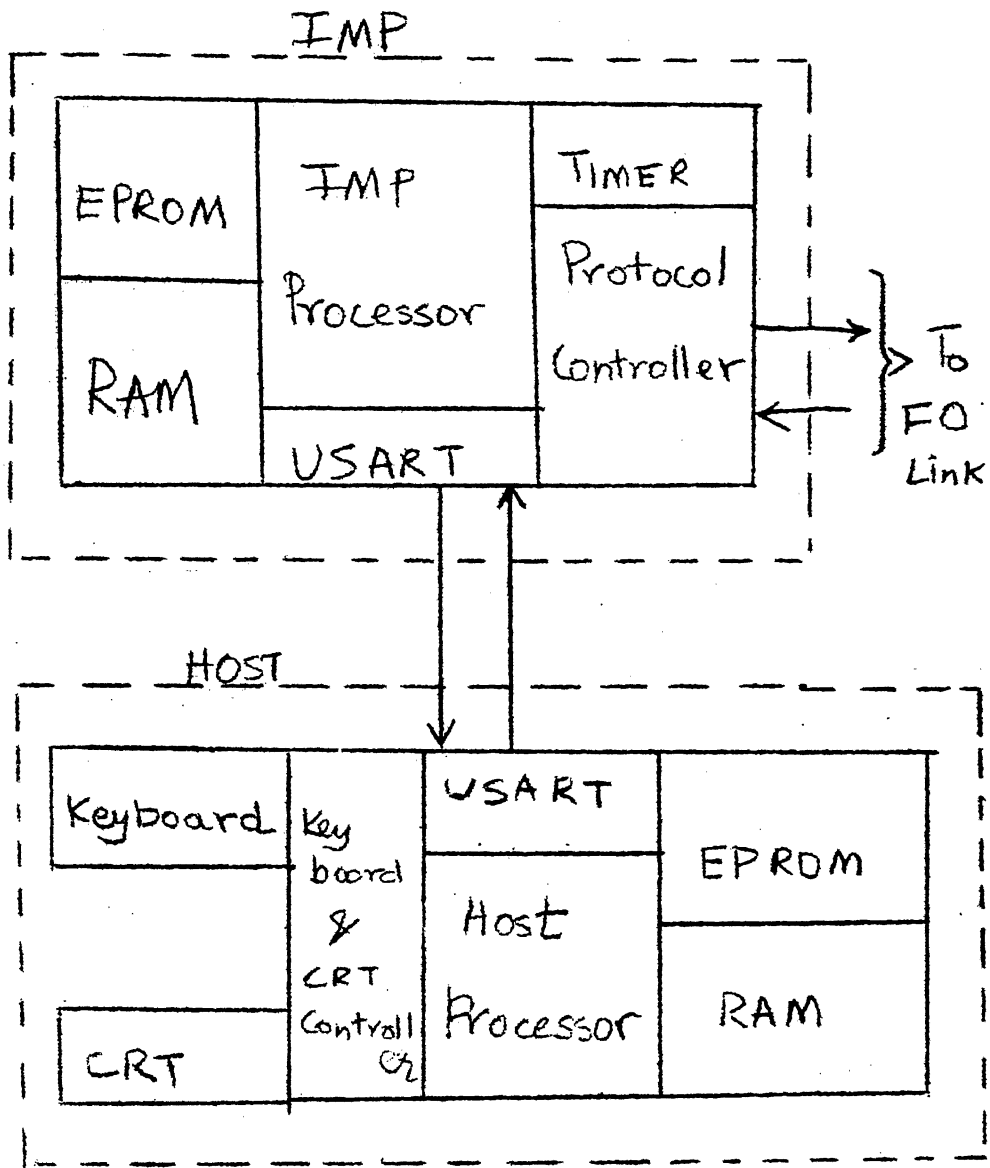


Fig 4.2. IMP-HOST Schematic
Block diagram.

Memory MAP:

4000H - 47FFH = Transmit buffer = 2K bytes

4800H - 3FFFH = Receive buffer = 2K bytes

5000H - 52FFH = Scratch pad

5800 - 5FFFH = System stack area

E000H - EFFFH = Link protocol resident ROM

Table 4.1

Port Address:

Device	Register	Port Address	Type
8273	Command	20H	Output
	Status	20H	Input
	Transmit interrupt	22H	Ipt
	RESET	22H	Opt
	Parameter	21H	Opt
	RESULT	21H	Ipt
	Receive Interrupt	23H	Ipt
	Data in	30H	Ipt
	Data out	40H	Ipt
8253	Control word	C3H	Opt
	Counter 0	C0H	Opt
	Counter 1	C1H	Opt
	Counter 2	C2H	Opt
8251	Control	F9H	Opt
	Status	F9H	Ipt
	Data in	F8H	Ipt
	Data out	F8H	Opt

Table 4.2

The schematic diagram of the IMP is shown in Fig. 4.3. A description of the hardware follows.

Central Processing Unit: The CPU is the Intel 8085 N-channel, 8-bit microprocessor. It has four vectored interrupt inputs. Two of the interrupts are being wired for the 8273(7.5 and 5.5). One of the other is wired to timer output (6.5). The CPU uses a multiplexed data bus. The address is split between the 8 bit address bus and 8 bit data bus.

Timer: The timer is the Intel 8253. It is^a programmable interval timer. It has a 3 independent 16 bit counters, programmable in several modes. The timer is used to generate an interrupt on terminal count. The time out interrupt is given for every 5 msec. This time is slightly greater than the time required for the sums of time required to send a frame time required to process a frame and time required to initiate an acknowledgement transmission and the time required to send the acknowledgement and process it.

USART: The universal synchronous - Asynchronous Receive Transmit IC 8251 is used to perform the IMP Host interface connection. The 8251 is programmed in the Asynchronous mode with the transmit and receive baud rates of 2.4K band. The CPU polls the Rx RDY bit of the status register for any keyed character from the host. To display a character on the

monitor, the CPU polls the RxRDY bit of the status register and sends it down via the serial link.

Random Access Memory: The Rams are 2114s. They are used for scratchpad area and for the receive and transmit buffers.

Multiplexer: The 74257 is a Quad Data Selector/Multiplexer. It is used for generating separate Memory Read, Memory Write, IO Read and IO Write signals.

Decoders: The 74138 is a 3 to 8 line Decoder/Multiplexer. It has been used to generate the chip select logic for the memory and the I/O ports. One of them is used for generating a low DACK signal for the 8273.

Read Only Memory: The 2716 is a 2K byte ultraviolet erasable and electrically programmable read only memory. The 2716 contains the object code of the designed protocol. The address of these ROMs range from E000H to EFFFH. There are two, 2K ROMs.

Protocol Controller: The 8273 is a programmable HDLC/SDLC protocol controller. It is a dedicated device designed to support the ISO/CCITT's HDLC and IBM's SDLC communication link protocols. A frame level command set is achieved by a unique microprogrammed dual processor chip architecture. This controller minimizes the CPU software by supporting a comprehensive frame level instruction set and by hardware implementation of low level tasks associated with frame assembly/dis-assembly.

Fig. 4.4 shows the functional block diagram of the 8273. The 8273 is used in the Asynchronous mode. Hence the data has been encoded/decoded in Non Return to Zero Invert code (NRZI). The receive clock is derived from the Received data using a digital phase locked loop (DPLL). The inputs to the PDPLL are the receive data in NRZI code and a clock which is approximately 32 times the baud rate. The $\times 32$ counter on board consists of a 7474 (flip-flop) and a 7493 (8 bit counter). The output of DPLL is connected to the receive clock. The DPLL can recover clock upto a maximum of 9.6 K baud data transfers. The 8273 achieves data transparency using a zero bit insertion/deletion technique. The frame check sequence (FCS) is automatically generated and appended before the final flag is transmitted. The frames are automatically checked for errors during reception by verifying the FCS. The 8273 recognizes and generates flags ($\emptyset 1111111 \emptyset$).

The 8273 communicates with the CPU by means of interrupts. The RST 5.5 is wired to the TxINT pin. The 8273

will cause an interrupt after the completion of execution of a transmit command. The result of the operation is placed in the TxINT Register whose contents are to be decoded as shown in Table 4.3.

The 8273 is being operated in the buffered, interrupt driven data transfer mode. The TxINT therefore goes high at the end of a frame and also at the end of transfer of a byte. The status register is interrogated prior to taking any further action. Data is transferred via the Data Out Register. Data from memory is written into Data Out Reg. by pulling the TxDACK low. The RST 7.5 is tied to the RxINT pin. The RxINT goes up after receiving a frame and also after receiving a byte. The status register must be interrogated to find the cause of the interrupt viz. data transfer or frame complete interrupt will require 3 successive reads, out of the RxInterrupt Reg. The 1st result must be decoded as shown in Table 4.4. The next two results read out of the RxINTR Reg. will give the length of the frame received.

4.4 IMP SOFTWARE:

4.4.1 Design Considerations:

The following are the points which provide the guiding philosophy for the implemented software:

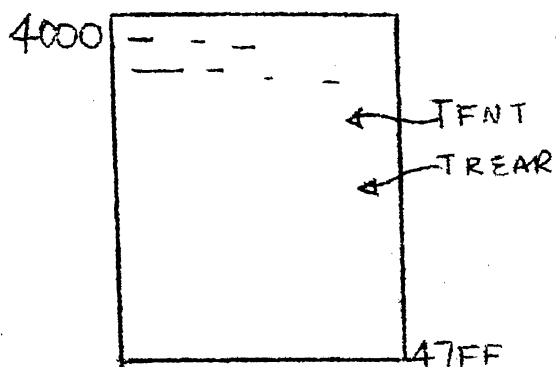
1. The aim is to design the operating system for the interface message processor. The host and the serial link are on either side of the IMP.
2. The above point entails us to design the data link and the network layer protocols.
3. The activities of the protocols have to be made user transperant.
4. The software must be absolutely modular to make it flexible and easily updatable.

The programs are modular in Design. This modularity enforces easy SW debugging and improved readability. Most of the SW manipulates the system buffers. Therefore it is essential to know how these system buffers are implemented.

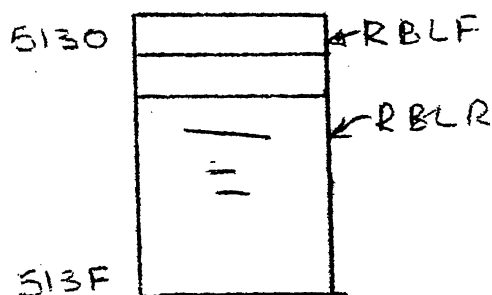
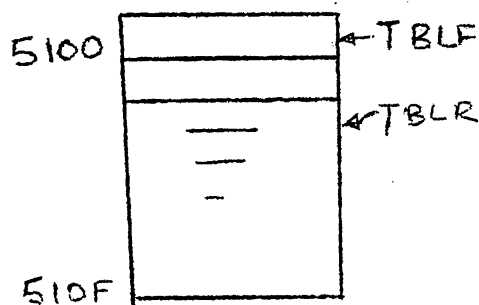
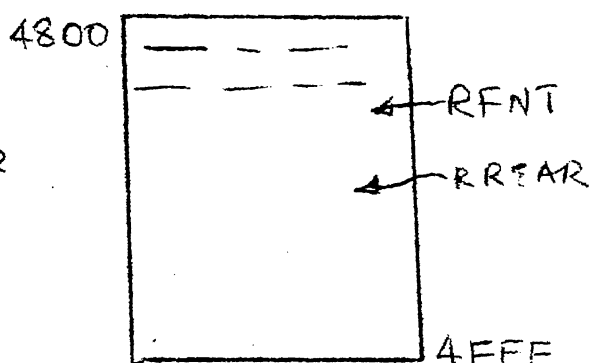
4.4.2 Buffer Data Structures:

There are four buffers in every unit. The Transmit buffer and the Receive buffer hold the out going and the incoming Packets, respectively. These are supported by the transmit packet length (TPL) buffer and the Receive packet length buffer (RPL) buffer. The TPL buffer holds the lengths of the packets in the receive buffer. ALL THE BUFFERS ARE CYCLIC QUEUES. In addition to the buffers a few bytes are used as stores for identifiers. The receive buffer and the

TRANSMIT BUFFERS; and structures



Receive Buffer; and structures



TFNT = Transmit Buffer Front
 RFNT = Receive Buffer Front
 TBLF = Transmit Packet Length Front
 NPKT = Number of Packets in Transmit Buffer
 NPKR = Number of Packets in Receive Buffer
 PKST = Transmit Packet Sequence
 PKSR = Receive Packet Sequence
 TREAR = Transmit Buffer Rear
 RREAR = Receive Buffer Rear
 RBLR = Receive Packet Length Rear
 TBLR = Transmit Packet Length Rear
 RBLF = Receive Packet Length Front

Fig. 4.4.b.

transmit buffer can hold a maximum of 8 packets of length 256 bytes or Less. The Transmit and Receive Buffer Structures are shown in Fig. 4.4.b.

4.4.3 System Routines:

The system software can be explicitly classified under the following categories:

1. System initialization routines
2. Command Processor
3. Link Control routines
4. User I/O routines
5. Interrupt Service routines

1. System initialisation routines:

The system initialisation routines comprises of the following:

i) MDIN: MODE INITIALISATION:

This routine will initialise all the registers of the 8273 and RESET the 8273. It will next define the operating environment of the IMP. The parameters to be set are:

1. Operating mode
2. Serial I/O mode
3. Data transfer mode

ii. GRCV : GENERAL RECEIVE:

It executes a general receive command. It will enable the receiver to receive another new packet.

iii. ERPRG: ERROR IN PARAMETER REGISTER:

This routine is called whenever there is an error in programming the parameter register. It will flash a message on the screen.

iv. CMDHP : COMMAND HELP:

This routine will list the various commands available for the user.

v. TINEN : TIMER INITIALIZE AND ENABLE:

This routine will initialise the 8253, as specified by the command word

vi. INIT : INITIALIZE THE SYSTEM:

This routine will preset the values into the variable identifier locations. It will also preset the pointers to the buffers. It will then execute the MDIN, DMIT, DMIR and GRCV routines.

vii. INITI : INITIALIZE:

This routine will execute the INIT and CMDHP routines and return control to the MAIN program.

2. Command Processor:

The command processor will initiate the corresponding routine's execution, whenever a command is given.

3. Link Control Routines:

The link control routines monitor the status of the link and send the packets across the link.

i. XMIT: TRANSMIT INFORMATION FRAME:

This will transmit a frame with the address, control and number of bytes as specified by the contents of the locations ADR, CTL, BLO and BHI. The expected response is a RECEIVE READY.

ii. XMIR: TRANSMIT RESPONSE FRAME:

This will transmit a frame with the address, control and number of bytes as specified by the contents of the locations ADRR, CTLR, BLDR and BHIR. The expected response is Unnumbered Ack.

iii. SABM : SET ASYNCHRONOUS BALANCE MODE:

When called, this routine will transmit a command frame with the code for SABM in the control field. The expected response is an Unnumbered Ack.

iv. UATX : UNNUMBERED ACKNOWLEDGEMENT TRANSMIT:

UATX will transmit a Response frame with the control code for UATX.

v. ABORT:

ABORT will transmit a command frame with the code for abort in the control field. The expected response is Unnumbered Acknowledgement.

4. USER I/O ROUTINES:

The functions of the host machine have to be simulated by the software. These routines help in achieving that end.

i. LOAD:

This routine enables the user to load data into the transmit buffer. This function is performed by the host in larger systems. This data is the one that is requested for transmission.

ii. DISPLAY:

This routine will display, on the monitor, the contents of the last received packet. In larger machines the hosts will do further processing on this data.

5. Interrupt Processing Routines:

The system is interrupt driven. The interrupts are the driving force for the system. Most of the prime functions are done by the interrupt routines, the following comprise the interrupt routines.

i. TXINT : TRANSMIT INTERRUPT ROUTINE:

The transmit interrupt routine is called at the end of every byte of data, transmitted. The logic will then initiate further actions depending on the outcome of the transmit interrupt result. The flowchart is given in the appendix.

ii. RXINT : RECEIVE INTERRUPT ROUTINE:

The receive interrupt routine is invoked for every byte of received data. The program logic will take further actions depending on the outcome of the receive interrupt results. The flowchart is given in the appendix.

iii. TOINT : TIMEOUT INTERRUPT ROUTINE:

This routine is called whenever a timeout interrupt occurs. A timeout interrupt will occur, if an acknowledgement is not received in the specified time. This is a measure to prevent the system from waiting infinitely for an acknowledgement (take care, the stop-and-wait protocol is implemented). This routine will transmit a frame a maximum of eight times, if the acknowledgement is not received, after which it will indicate that the link is faulty. The flowchart is given in the appendix.

CHAPTER 5

CONCLUSION

The design and implementation of a Fiber Optic point-to-point computer communication link has been discussed in the previous chapters. Now comes the question of building Networks. A Network is a collection of interconnected Hosts, terminals and peripherals. Designing the topology can be divided into two subproblems, the backbone design and the local access design, as in Fig. 5.1. The constraints for the backbone design are connectivity and delay. Techniques from graph theory are helpful in dealing with connectivity analysis. The queueing theory is a valuable tool for performing Delay Analysis. The local access network is generally designed Heuristically. The topology for implementation is best left to the network designer.

The Hosts, terminals and peripherals are connected by means of a physical communication channel. The communication medium is error prone. The data link layer protocols enforce error free communication over an error prone physical channel, by employing certain protocols. The implemented system uses the simplest of the Automatic Repeat Request Protocols, viz. STOP-and-WAIT. The channel utilization as a result of this is analysed.

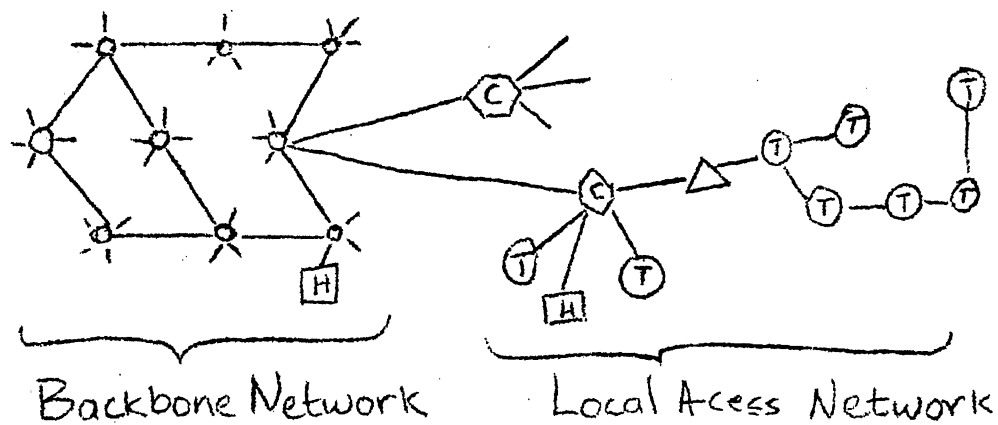


Fig. 5.1

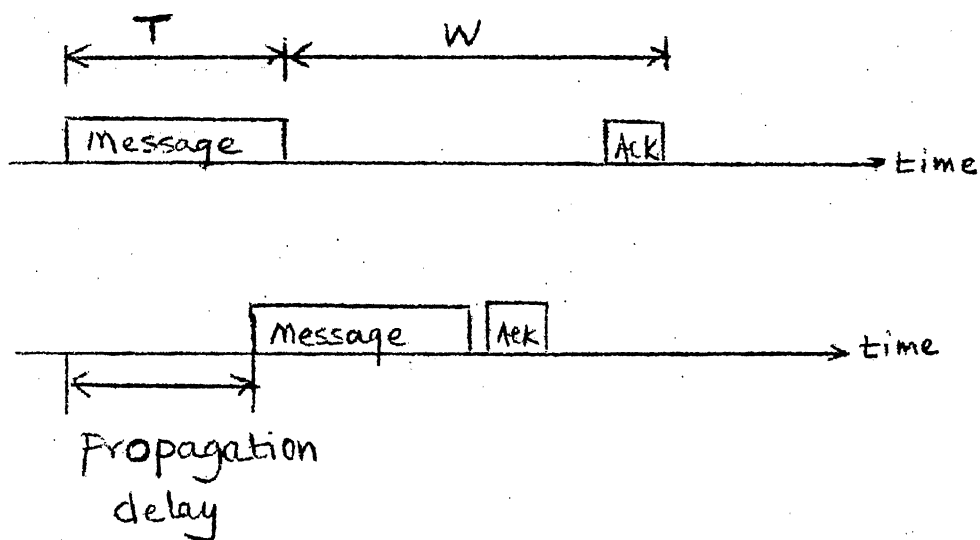


Fig. 5.2

The stop and wait protocols involves wastage of some time, because of waiting for acknowledgements. The situation is shown in Fig. 5.2. T is the message transmission time and W is the waiting time before the next message can be transmitted. The message transmission takes place only $T/(T+W)$ of the available time. If ' P ' be the probability of an erroneous message, only $(1-P)$ of the transmitted messages will be received correctly. The channel utilization (U) can be defined as

$$U = \frac{T}{T+W} \times (1-P)$$

Let the speed of transmission be v bps and the message length be n bits, then

$$U = \frac{n}{n+Wv} (1-P)$$

The waiting time consists of the round trip propagation delay, transmission time for the acknowledgement frame and the Interrupt service times. The Interrupt service times are generally very small and are negligible when compared without two. The propagation delay can be calculated from $t = \frac{d}{v}$, where d = distance and v = velocity of light in the medium. For an optical fiber the velocity in the core region is about 2×10^8 m/s because the refractive index of the core is about 1.5. Therefore the propagation delay for 100 m of the optical fiber cable is 0.5 μ s.

For the Fiberoptic link:

Propagation delay = $0.5 \mu\text{s}/100\text{m}$

Transmission speed = 9600 bps

Length of acknowledgement frame = 32 bits

Waiting time = time to transmit an Ack. frame
+ propagation delay

= $3.33 \text{ ms} + 0.5 \mu\text{s}$

3.33 ms

The advantage of the fiber optic channel is that it has reduced propagation delays. Typical propagation delays for a co-axial cable and an optical fiber are 30 ms/100 km and 0.5 ms/100 km, respectively. The optical fiber channel is virtually noise free. The bit error rate of the HFBR-2001 receiver is 10^{-9} .

The channel utilization for different packet lengths are as shown in Table 5.1. The channel utilization for a 1 K (1024) byte packet is 99.61% and the effective rate of transmission is $0.9961 \times 9600 = 9563$ bps. Thus we see that the stop and wait protocol when implemented on an optic fiber channel produces results which are better than for other mediums.

Table 5.1

Actual data rate = 9600 baud

No. of bytes per packet	channel utilization %	Effective transmission rate bps
64	94.33%	9056
128	97.08	9320
256	98.52	9458
512	99.30	9533
1024	99.62	9564
2048	99.81	9582

The implemented system works well for medium data rates, but we are not making use of the large BW of the OF link. Hence the data rates can be increased. This involves building additional circuits for clock recovery and Direct Memory access controller. The DMA will perform faster data transfers than it takes for the CPU. Manchester coding can be employed, because clock recovery is simpler [22]. The circuits for manchester encoder and clock recovery is given in Appendix. Baud rates of 64 Kbps are achievable using additional DMA and clock recovery circuitry.

One more consideration for improvement could be implementing a better error recovery procedure, than stop-and-wait. The sliding window protocols with window sizes greater than one offer better channel utilization, at higher loads. The Piggyback feature for Acknowledgement transmission can be incorporated by modifying the software.

5.1 Suggestions for Further Work:

1. The Network layer in a point-to-point network is concerned with routing and congestion control. When a frame arrives at an IMP, the data link layer strips off the data link header and trailer and passes off what is left, called a PACKET, to the network layer. The network layer must then decide which outgoing line to forward the packet on. It would

be nice if such decisions could be made so as to avoid having some lines congested and some idle. Hence congestion control is intimately linked with routing. It can be taken as an exercise to design, develop and implement new routing algorithms and congestion control procedures.

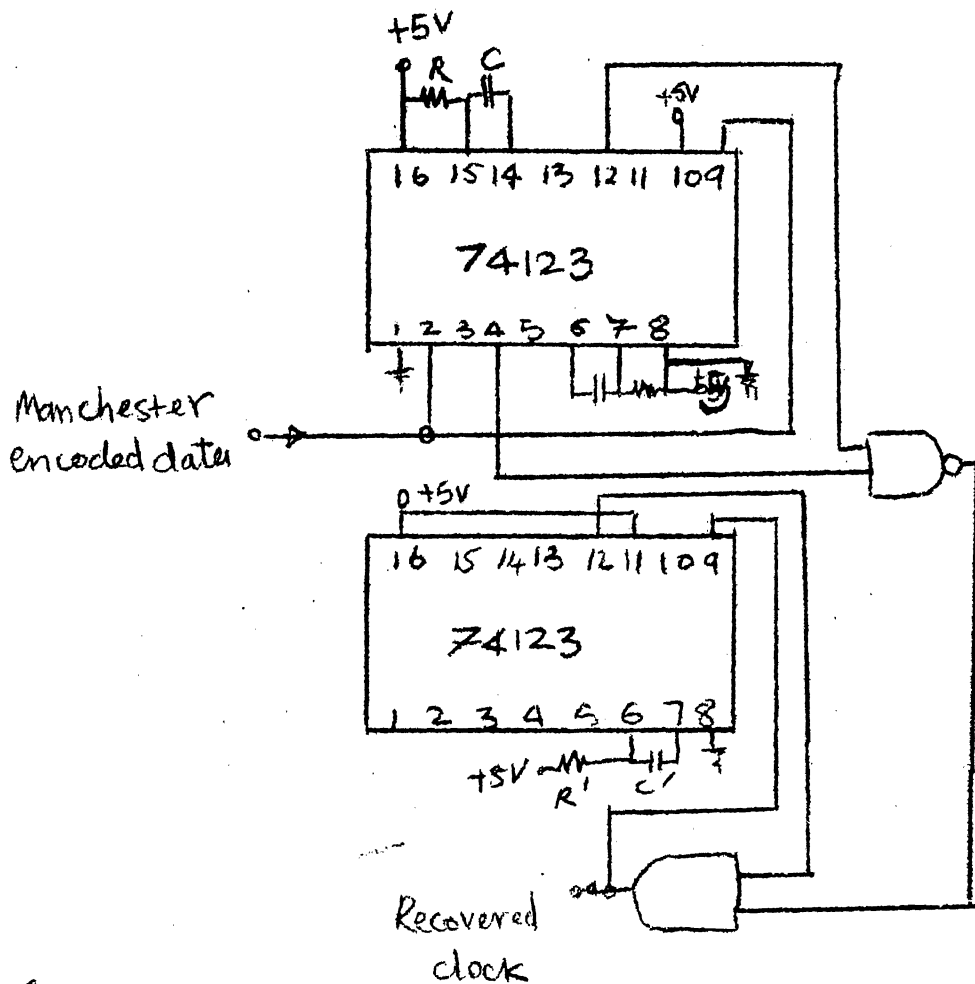
2. Initially this project was aimed at developing an Intermediate message processor to link the PDP11 and DEC10 computers, via an optical fiber link. To accomplish such a task, similar design procedures as in this work are to be adopted. The existing system architecture must be modified to include a DMA controller. The implementation will be different because now we will have a whole new set of bus structures, system organisation, etc.

3. A tree structured point-to-point link can be implemented. The configuration of the network is shown in Fig. 3.1. The multiplexers can employ frequency division multiplexing (. FDM). Concentrators employ the Asynchronous Time division multiplexing technique (ATDM). Details on concentrators and multiplexers can be found in [20]. Already the point-to-point link is functional. Only additional interfacing circuitry and multiplexers are to^{be} built to complete the network.

Another variation is to use the optic fiber link as a data gateway to interconnect two different networks on either ends. ex. one can have an SDLC loop network on one end and an Ethernet on the other.

APPENDIX

1. HFBR - 1001
2. HFBR - 2001
3. HFBR - 3000
4. CLOCK RECOVERY FOR
MANCHESTER ENCODED DATA.
5. FLOW CHARTS.



$$\text{freq} = 25 \text{ KHz}$$

$$R = 1 \text{ K}\Omega$$

$$C = 0.047 \mu\text{f}$$

clock

$$R' = 3.3 \text{ K}\Omega$$

$$C' = 0.047 \mu\text{f}$$

$$\text{freq} = 10 \text{ KHz}$$

$$R = 1 \text{ K}\Omega$$

$$C = 0.094 \mu\text{f}$$

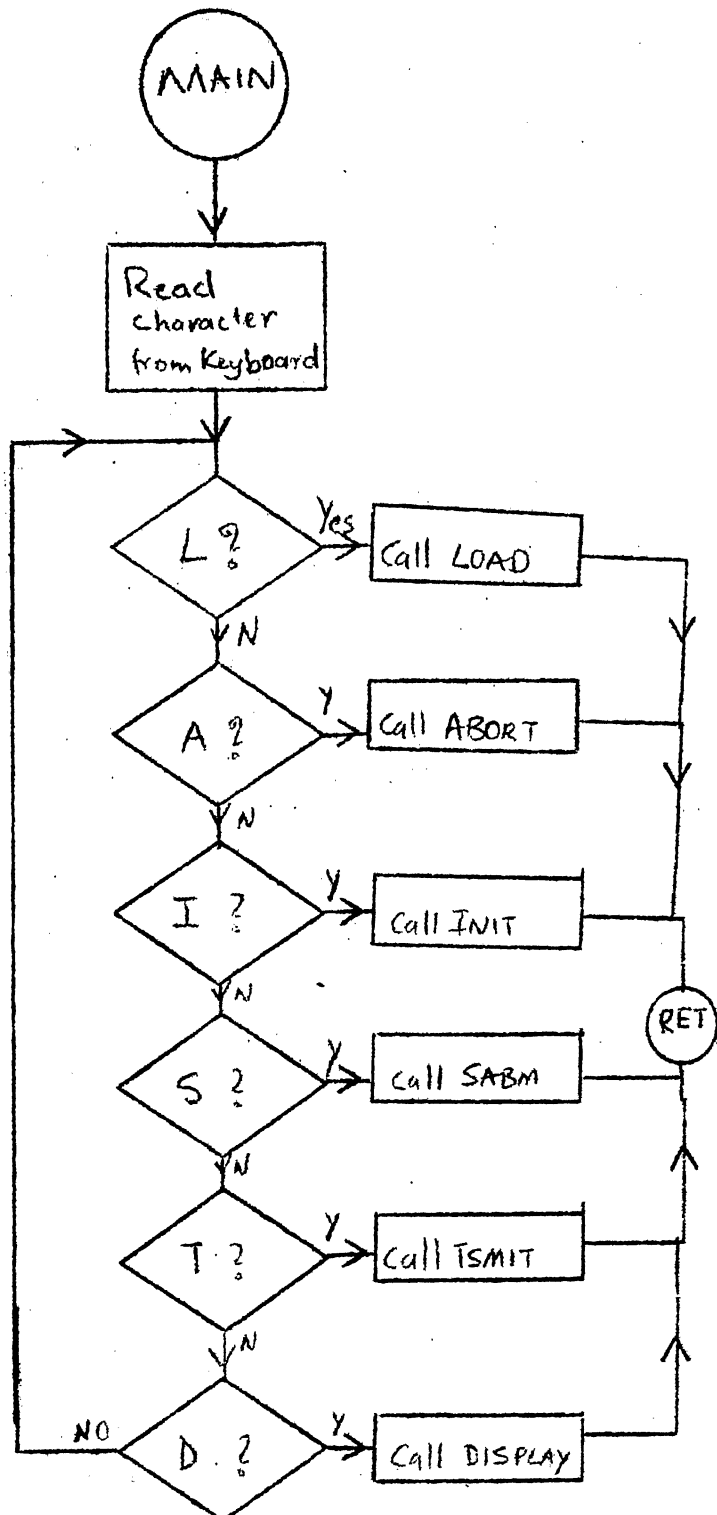
$$R' = 3.3 \text{ K}\Omega$$

$$C' = 0.094 \mu\text{f}$$

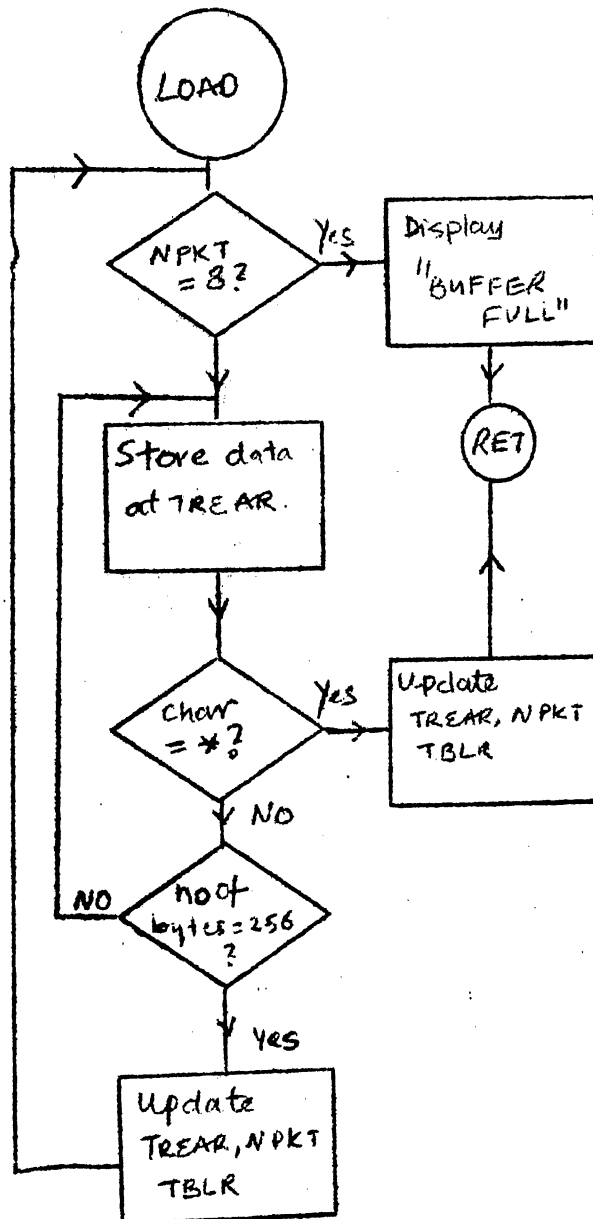
A4: Clock recovery circuit.

A5: FLOWCHARTS:

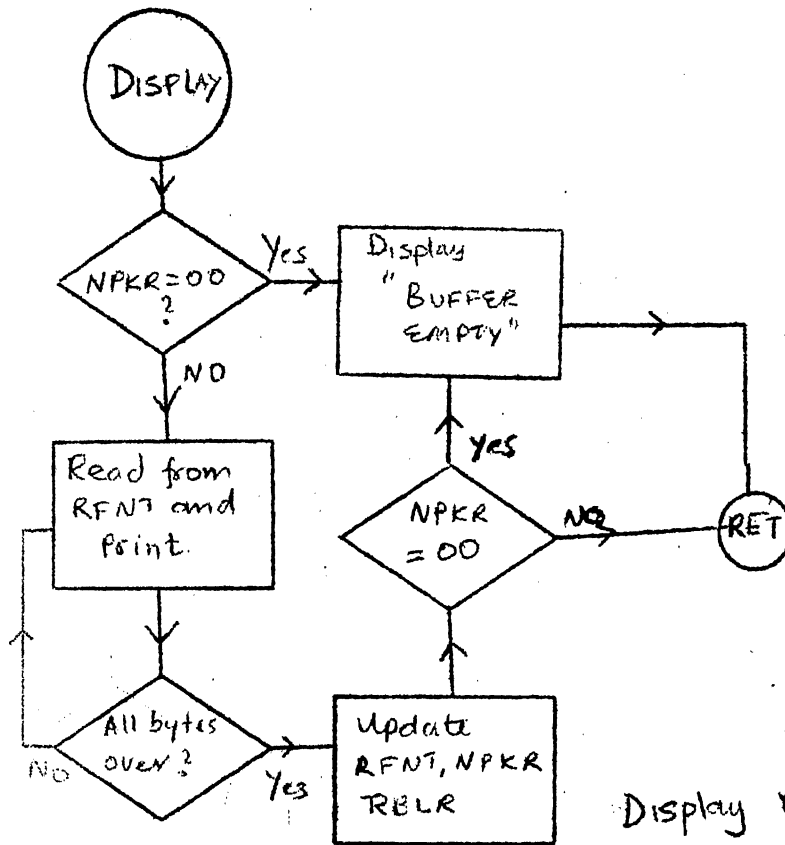
70



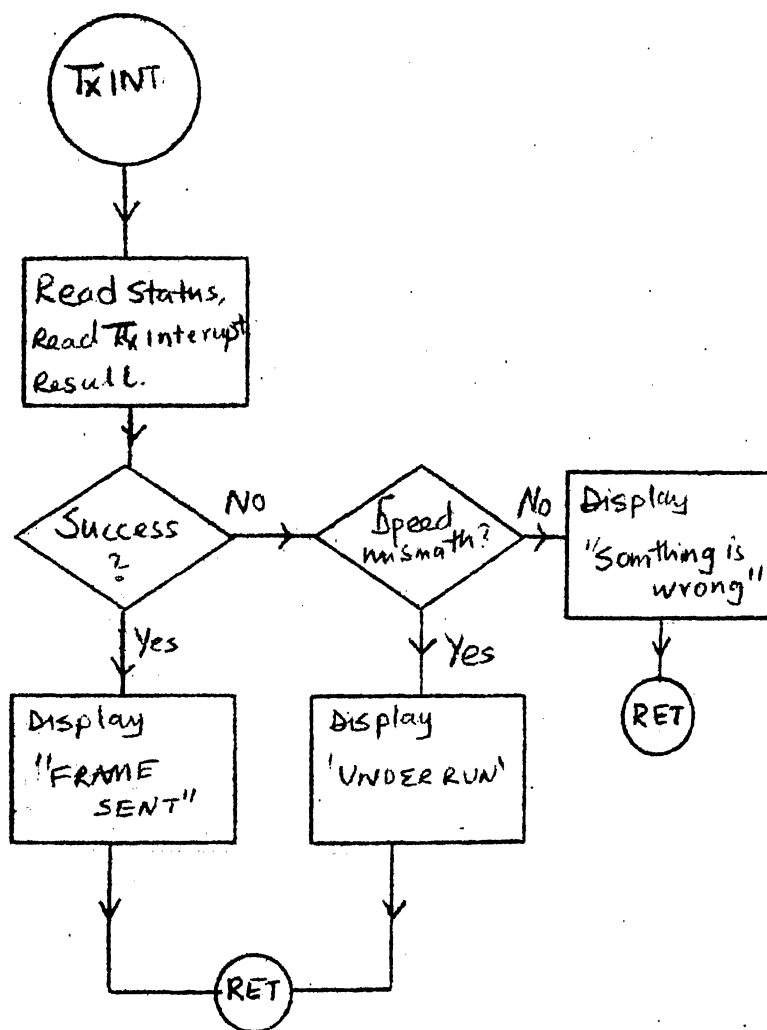
COMMAND PROCESSOR.



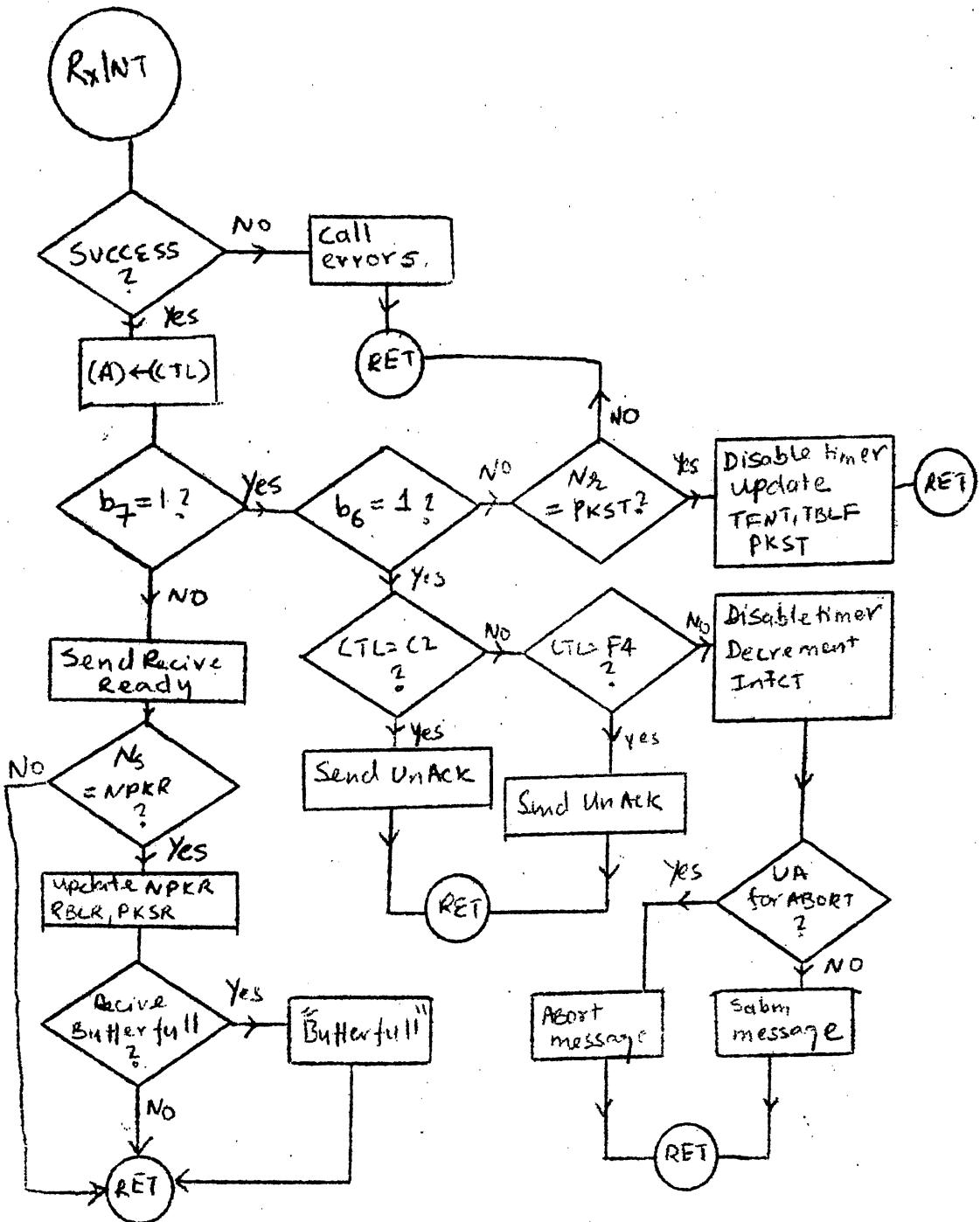
LOAD : Package size, and store in Tx Buffer.



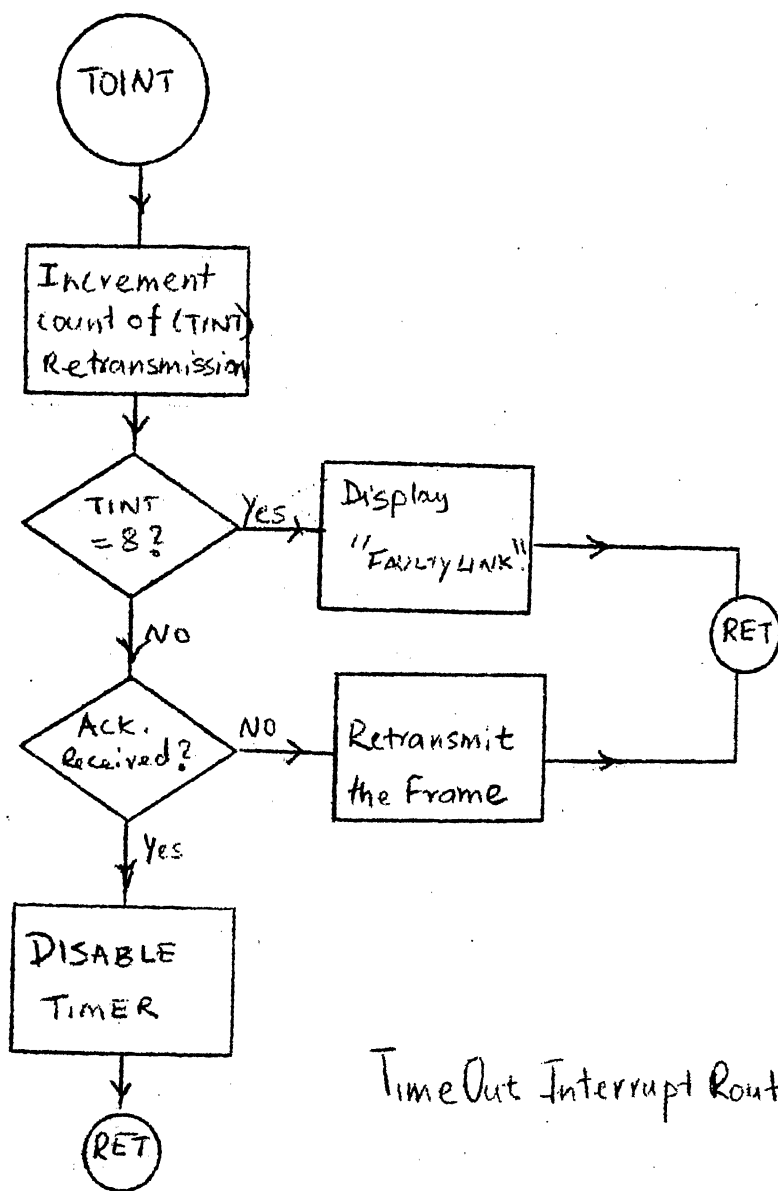
Display routine.



TRANSMITTER INTERRUPT ROUTINE FOR END OF FRAME.



RxINT: Receiver Interrupt Routine for End of Frame.



TimeOut Interrupt Routine

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